M.A. Alspaugh, USA

The Evolution of Intermediate Driven Belt Conveyor Technology

Abstract

The driving force behind most technology advances is need. In the early 1980s, underground coal miners in the USA wanted to build longer conveyors to handle larger capacities but continue to use fabric reinforced belting and mechanical fasteners. Intermediate driven conveyors were certainly the answer but achieving reliable designs required a significant learning curve. Basic design methodologies had to evolve including advanced simulation of starting and stopping, and complex control techniques and logic. Some components also evolved as specific performance requirements changed. Today, in addition to underground mining, the technology has been used extensively in the tunneling industry where the need was belt tension control to negotiate tight horizontal curves. Although not used extensively on the surface yet, the lessons learned will find their way to long overland surface conveyance where smaller components are more available and reliable. This paper will document the evolution of intermediate drive technology over the last 30 years and show examples of its current use.

1. Introduction

The idea of distributing power in multiple locations on a belt conveyor has been around for a long time. The first application in the USA was installed by Continental Conveyor & Equipment Co. at Kaiser Coal in 1974. This was the first of two rubber tire driven conveyors installed. The second, at Brewster Phosphates was 4 426 m in length and included 11 × 150 kW booster drives [1]. In 1978 in Germany, an incline conveyor 720 m in length with 170 m of rise carrying 950 t/h of coal was installed using a 4 × 80 kW main drive and 3 × 80 kW belt-on-belt intermediate drive [2]. It was shortly thereafter that underground coal mining began consolidating and longwall mines began to realize tremendous growth in output. Mining equipment efficiencies and capabilities were improving dramatically. Miners were looking for ways to increase the size of mining blocks in order to decrease the percentage of idle time needed to move the large mining equipment from block to block. Face widths were increasing and panel lengths were increasing.

When panel lengths were increased, conveyance concerns began to appear. The power and belt strengths needed for these lengths approaching 4 km to 5 km were much larger than had ever been used underground before. Problems included the large size of high power drives not to mention being able to handle and move them around. And, although belting technology could handle the increased strength requirements, it meant moving to steel reinforced belting that was much heavier and harder to handle and more importantly, required vulcanized splicing. Since longwall panel conveyors are constantly advancing and retreating (getting longer and shorter), miners are always adding or

Mr. Mark A. Alspaugh, Principal Systems Engineer, Overland Conveyor Company, Inc., 10765 W. Ontario Place, Littleton, CO 80127, USA.
Tel.: 001 303 973 7357; Fax.: 001 303 973 8257;
E-mail: alspaugh@overlandconveyor.com

Details about the author on page XXX.

Fig. 1: Dallas Area Rapid Transit Project (photograph courtesy of Continental Conveyor)

removing rolls of belting from the system. Moreover, since vulcanized splicing takes several times longer to facilitate, lost production time due to belt moves over the course of a complete panel during development and mining would be extreme.

Although the benefits of distributing power at various intermediate locations along a conveyor had been known for many years and attempted a few times, the concept was still uncertain. Now the need surpassed the risk and the application of intermediate drives to limit belt tensions and allow the use of fabric belting on long center applications was actively pursued.

Today, intermediate drive technology is very well accepted and widely used in underground coal mining. Many mines around the world have incorporated it into their current and future mine plans to increase the efficiency of their overall mining operations. A related industry, tunneling (Fig. 1) has also adopted the technology with gusto and taken it to even higher levels of complexity and sophistication. Although aboveground overland conveyors have not extensively used this technology to date (Fig. 2), applications are now starting to exceed the limits of even steel reinforced belting and intermediate drives will find there way into the light as future needs arise.

Fig. 2: Seven Oaks Dam / CBPO (photograph courtesy of Continental Conveyor)

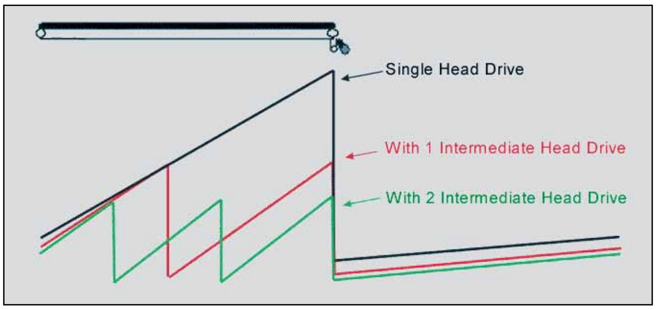


Fig. 3: Belt tension diagramm

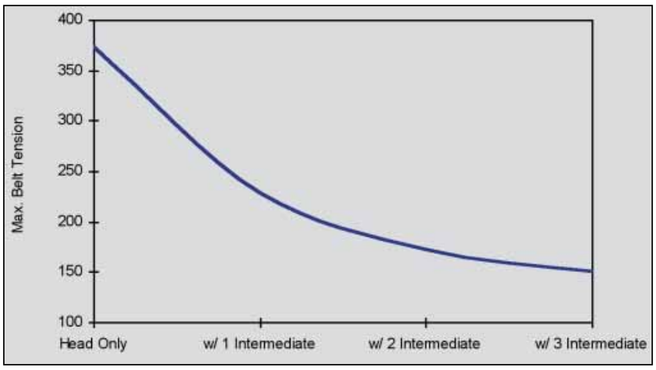


Fig. 4: Maximum belt tension vs. number of drives

2. The Benefits

The tension diagram in Fig. 3 shows the simple principal and most significant benefit of intermediate belt conveyor drives. This flat, head driven conveyor has a simple belt tension distribution as shown in black. Although the average belt tension during each cycle is only about 40 % of the peak value, all the belting must be sized for the maximum. The large drop in the black line at the head pulley represents the total torque or power required to run the conveyor.

By splitting the power into two locations (red line), the maximum belt tension is reduced by almost 40 % while the total power requirement remains virtually the same. A much smaller belt can be used and smaller individual power units can be used. To extend the example further, a second intermediate drive is added (green line) and the peak belt tension drops further. However, the benefit is less as the maximum tension is only reduced by 25 %. Moreover, each additional drive produces exponentially decreasing benefits. This is reflected in the Fig. 4 curve.

3. Types of Intermediate Drives

3.1 Tires

As in any new technology, many things are tried and often discarded for various reasons. One of the initial trials to transmit power to the belt without wrapping around a flat pulley was through common car tires (Fig. 5). Drive traction was provided by pressing tires above and below the belting.

3.2 Linear (Belt-on-Belt)

Another arrangement that was more successful was called belt-on-belt or linear drives (Fig. 6). These linear drive arrangements were simply small conveyors built inside the larger conveyor. Drive power was transmitted to the small belt through a traditional flat pulley, which transmitted torque to the larger conveyor through friction between the two belt surfaces. This scenario was particularly encouraged by the belt manufacturers as the elimination of transfer points was expected to greatly extend the belt wear life.

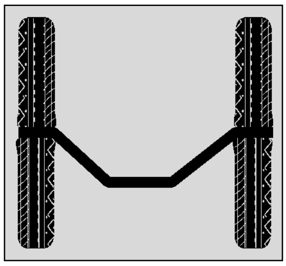


Fig. 5: Intermediate drive using tires to transmitt the power

Several of these conveyors were installed in the mid to late 1980s. The first significant application in the USA was at USX Mine 37 in Lynch, Ky and was installed in 1985. It was a mainline underground coal application 1524 mm wide, carrying 4 600 t/h. It had 2 238 kW attached including four belt-on-belt intermediate drives. Although this mine is no longer active and the conveyor gone, this is still one of the most impressive applications of the early technology.

The problems included the extra expense of the driving conveyor. It was common to provide one foot of driving belt length for every horsepower installed therefore the above USX application had 4 × 200 m driving belts for a total of 1 600 m of extra belting not to mention the many extra pulleys, take-ups, etc. In the initial 1978 German installation, the driving belt was 200 m long, which was 28 % of the total conveying length. The second problem was discovered when it was later determined interactive torque control was necessary (see below). There was no easy way to monitor what the drive needed to be doing based on material load.

3.3 Tripper

The industry gradually migrated in the late 1980s to the "tripper" drive configuration shown in Fig. 7. When the industry went back to this conventional method of driving over a flat pulley, the technology become widely accepted and progressed rapidly. Methods of measuring belt tension to monitor material load and control torque were developed. The ease of installation and removal made them quickly favored by the mines. In addition, it was quickly discovered that the "tripper" transfer was not nearly as hard on the belt as a conventional transfer between two conveyors as they are always in-line and the discharging belt speed and receiving belt speed must always be the same since they are the same belt. Spillage and cleanup was minimal.

Today, there are no belt-on-belt drives running in the US and all new installations are as Fig. 7 or a variation of this "tripper" theme.

4. Torque Control

Of course, every significant benefit comes with inherent negatives or risks. In the case of intermediate drives, the most significant risk is the added complexity of design and implementation. Distributing power along a flexible conveyor belt requires detailed attention to how the power is applied at each drive location relative to all the possible load variations that might exist. If

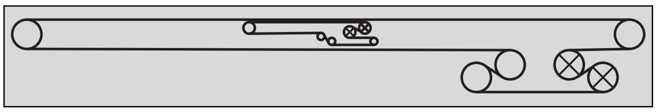
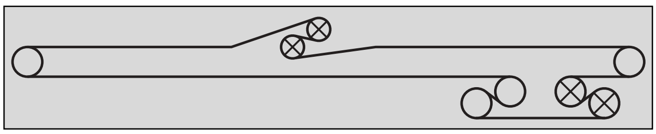


Fig. 6: Belt on belt or linear drives arrangement

Fig. 7: Basic layout of today commonly used tripper drive configuration



too much power is applied at the wrong location, belt tensions can drop too low and drive slip or belt sag and material spillage can occur. If too little power is applied at one drive location, other drive locations may become overloaded and stall. Of course, this is of interest during normal running conditions but is especially critical during the transient condition of starting and stopping as belt tensions are fluctuating due to the inherent flexible nature of the belting. Since our ultimate goals are to use lower strength (low modulus) fabric belting on long center conveyors, dynamic concerns and potential problems are magnified.

In early intermediate drive applications little thought was put into the control of drive torque. With single drive location conveyors used up to this point, torque control during acceleration was typical to control the acceleration ramp but no control was used while running. Although some smaller intermediate driven conveyors were successful without running torque control, it was soon concluded the complexity of most applications required torque control while running as well. And many of the traditional acceleration torque control components in use at that time including wound rotor motors, reduced voltage starters and scope tube fluid couplings did not provide the ability or the accuracy necessary to properly control torque continuously.

4.1 Hydroviscous Clutch

One method that did provide the necessary characteristics was hydroviscous clutching devices such as the Dodge CST (Fig. 8). Although it was traditional to vary the clutch pressure during acceleration and lock the clutch during running, it was found the clutch could be left in constant slip state which provided the means to control torque at all times. And, since the clutch was on the low speed side of the reducer, the clutch provided adequate precision.

4.2 DC and VFD

Later an old technology, DC drives, was brought back to belt conveying because of its inherent ability to provide precise torque control . DC drives were quite common for several years and are still in use today on many applications. But on new applications today, variable frequency drives (VFD) have replaced DC because of maintenance and cost issues while still providing excellent torque control.

4.3 Variable Fill Fluid Couplings

Intermediate drive technology and the need for precise torque control have helped change the belt conveying industry. Just as VFD's are quite common today in belt conveyance, fluid coupling manufacturer Voith developed a new TPKL product (Fig. 9) because of this need for precise torque control. Infinitely variable

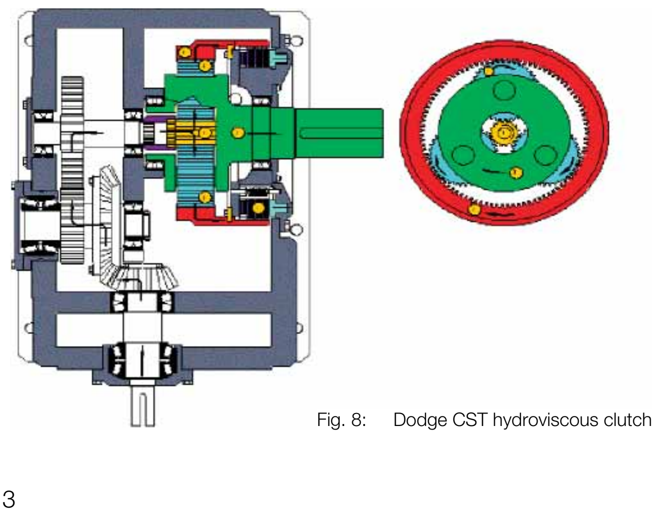


Fig. 8: Dodge CST hydroviscous clutch

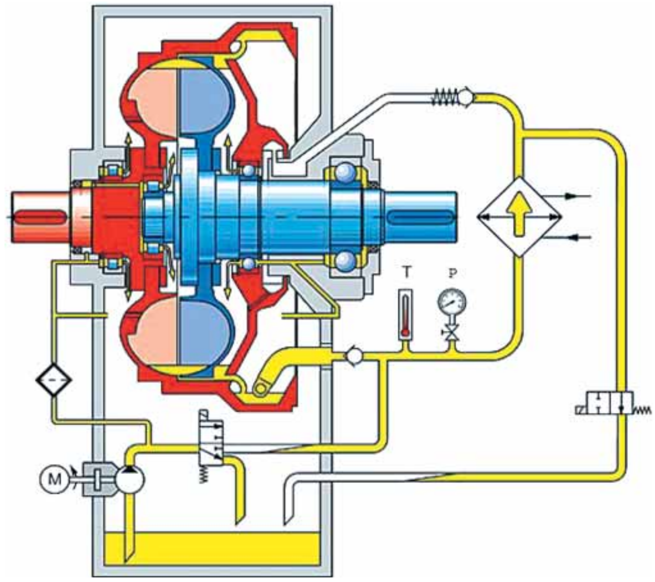


Fig. 9: Voith TPKL variable fill fluid coupling

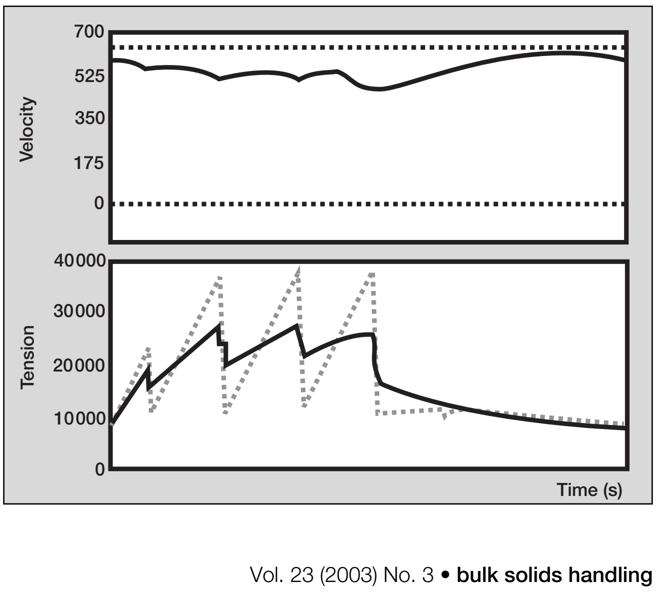
adjustment of the fill level (0 % to 100 %) is possible. The speed of the conveyor can be adapted through the changed coupling slip and load sharing is possible with any number of drives.

5. Dynamic Analysis

Of course, having equipment that can provide the required performance is critical but understanding what performance characteristics are required and developing the proper control logic is just as important.

New design methodologies had to be developed to properly model critical component requirements including the belt, pulleys and take-up. Traditional static analysis techniques as described in CEMA [4] were generally adequate (with modification to allow distributed horsepower) for modeling running conditions, but the rigid body method employed to analyze starting and stopping was inadequate. The idea of analyzing conveyors as flexible systems (dynamic analysis) was first introduced in 1974 by FUNKE [5] but was not yet widely used in the 1980s due to its complexity and cost. However, the lower stiffness of fabric belting and greater inherent elongation along with the longer lengths employed with intermediate drives soon revealed significant transient tensions and the more advanced dynamic simu-

Fig. 10: Belt velocity and belt tension vs. time at an intermediate drive



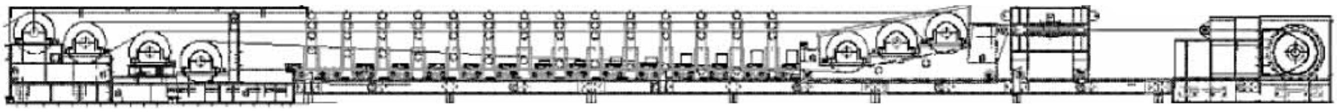


Fig. 11: Take-up unit with integrated belt storage

lation techniques were soon employed [6]. Dynamic analysis has proven invaluable in setting up complex starting control algorithms as well as defining more stringent and complex requirements of the take-up device and should be utilized on all intermediate drive applications (Fig. 10).

6. Take-up

Since intermediate drives are used extensively in underground mining, mechanical take-ups in the form of hydraulic cylinders and mechanical sheaving were commonly employed. And since intermediate drives were mostly used on longwall panel conveyors either advancing or retreating, belt storage had to be incorporated into the take-ups (up to 450 m) making these units very large and complex (Fig. 11). In addition to increased drive torque control requirements, intermediate driven conveyors also demanded increased performance from the take-up device in terms of reaction time, speed and tension control. Hydraulic cylinders could no longer provide the performance required.

Significant work went into the development of "constant tension" hydraulic winch take-up devices and then to electric "flux vector" winches (Fig. 12). These devices provided increased controllability and response time and could be equipped with load cell feed back mechanisms to constantly monitor and control belt tensions if required. This gave the conveyor designer increased flexibility to vary take-up tensions during starting or stopping and sometimes even during normal running operation.

Fig. 12: Electric "flux vector" take-up winch (photograph courtesy of Continental Conveyor)

7. Underground Coal Applications

Today, intermediate drives are readily accepted in underground coal mining around the world. A recent survey of the 50 USA longwall mines showed 60 % were currently using or would be using intermediate drives in the near future. A longwall panel with two trippers drives was recently installed in England and many have been employed in Australia.

A sampling of current systems in operation around the USA include (Tabel 1).

At MinExpo 2000 in Las Vegas, NV, USA, P.K. Sollars, Maintenance Manager at RAG Twentymile Coal Co. presented the evolution of their belt conveyance system since the mine began longwall operations in 1989 [7]. Intermediate drives have been an integral part of their conveyance system since the beginning and many technology innovations have evolved at this mine. Two of the most impressive conveyors presented included the conveyor with the most attached power in the USA and a unique panel application utilizing intermediate regenerative drives and intermediate braking.

The 2 Main North Conveyor (Fig. 13) at Twentymile Coal is 2 271 m in length with 268 m of lift. It is designed to carry 4 550 t/h and has 5 371 kW (16 motors) attached including the three tripper drives.

The 9 Right Panel Conveyor (Fig. 14) at Twentymile Coal was operated in 1995-96. It was 5 377 m in length and included a 159 m decline and 185 m incline. This profile included both very high power conditions and very high regenerative conditions. This was the first application of an intermediate braking station used in conjunction with a tail brake requiring very complex stopping control algorithms.

This technology has since been extended to include multiple intermediate regenerative drives at Twentymile Coal as they continue to push the technology limits.

Fig. 13: Intermediate drive layout of the 2 Main North Conveyor at Twentymile Coal, USA

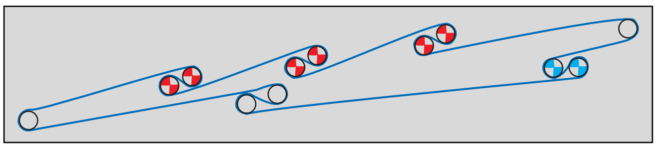


Table 1: Some examples of belt conveyor systems with intermediate drives operating in underground mining around the USA

Location	Width (mm)	Length (M)	Capacity (t/h)	Installed Power (kW)	Intermediate Drives	Drive Type
Alabama	1 524	3 350	4 000	1 790	1	Hydroviscous Clutch
Colorado	1 524	2 271	4 000	5 371	3	CST
Colorado	1 800	5 377	5 000	1 940	2	CST
Illinios	1 350	4 268	2 200	1 194	1	VFD
Kentucky	1 524	3 658	3 500	2 685	3	DC
Pennsylvania	1 524	4 410	4 000	2 237	2	CST
Utah	1 524	5 091	3 200	2 984	2	VFD
West Virginia	1 524	6 097	3 500	3 357	4	DC

Project/Location	Width (mm)	Length (M)	Capacity (t/h)	Horizontal Curves	Minimum Radii	Installed Power (kW)	Intermediate Drives	Installation Completed
DART/USA	750	5 395	725	13	300	600	2	1994
TARP/USA	900	13 985	1 270	17	300	2 244	10	1996
Yucca/USA	900	7 900	1 000	3	300	969	6	1997
CTRL/ UK – P240	800	2 × 4 700	800	3	2 500	480	1	2002
CTRL/ UK – P250	800	2 × 5 300	800	3	2 500	640	2	2002
UTE Guadarrama North #3	900	13 377	1 150	2	7 000	1 120	3	2003
UTE Guadarrama North #4	900	15 000	1 150	2	7 000	1 280	3	2003
Barcelona Metro UTE Linea 9	1 000	8 390	1 500	6	280	1 600	9	2003

Table 2: Examples of tunneling projects using conveyors with intermediate drives

8. Tunneling Applications

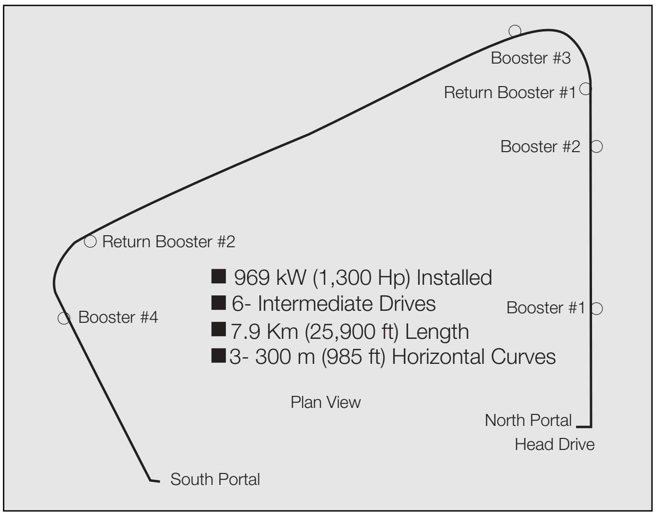
Intermediate drive technology has been utilized in the international tunneling/construction industry for approximately 15 years. The majority of the larger tunneling applications are suited for the technology, due to tunnel diameter, tunnel length and the amount of material to be conveyed/removed. Most applications utilizing conveyors are in the range from 3 000 m to 20 000 m however, the tonnage is low. Due to low tonnage requirements and size constraints, tunnel conveyors are relatively narrow and low strength belts must be used to accommodate the narrow widths. Utilizing intermediate drives allows the contractor to locate a storage unit outside the tunnel and install all belting from one location throughout the project.

Horizontal curves are often required in tunnels and intermediate drives are often used as a method of maintaining low and more consistent belt tensions in these areas allowing conveyors to negotiate horizontal curves as small as 250 m. Single flights conveyors have been designed and operated with ten (10) trippers and up to 17 horizontal curves.

A sampling of tunneling systems both past and present is presented in Tabel 2.

In May 1995, the US Department of Energy awarded The Conveyor Co of Sibley IA the contract to build a conveyor to follow the tunnel-boring machine at the Yucca Mountain Nevada Nuclear Waste Depository (Fig. 15). The conveyor included three horizontal curves turning a total of 208 degrees. Six intermediate drives (4 carry and 2 return) were incorporated to handle the 300 m horizontal radii. The conveyor finished the project in April 1997.

Fig. 15: Intermediate drives configuration of the conveyor contructed for the tunneling project at the Yucca Mountain Nevada Nuclear Waste Depository



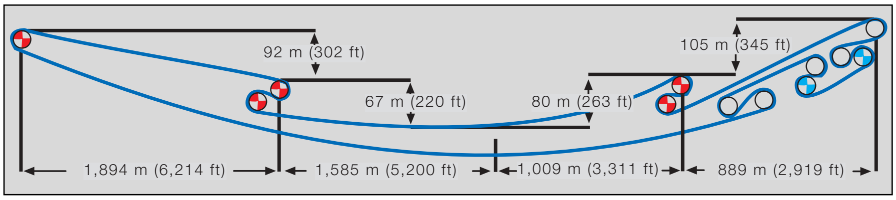


Fig. 13: Intermediate drive layout of the 9 Right Panel Conveyor at Twentymile Coal, USA

9. Conclusions

Intermediate drive technology has successfully transitioned from a new idea to mature and proven. Over many years, many lessons have been learned and conquered. The precision drive torque characteristics required has contributed to the significant improvements in drive methods available today and other components such as take-up methods have improved as well.

There are many ways to transport bulk material from one point to the next and no one technology is right for all applications. In surface conveying, the need to reduce belt tensions is not as significant as in underground applications so it has been utilized very seldom. However, conveying applications are continuing to get longer and intermediate drives coupled with horizontal curves can provide more efficient solutions to many of today's bulk material transport needs. There is no doubt intermediate drive technology should be and will be considered a viable option in surface overland conveyors in the future.

References

[1] McGaha, J.R. and Dos Santos, J.A.: Modern continuous haulage systems and equipment; bulk solids handling Vol 17 (1997) No 3, pp. 379-390.

[2] Bahke, T.: Dimensioning and application of belt conveyors with intermediate drive (T-T System); bulk solids handling Vol 2 (1982) No 1, pp. 47-51.

[3] Alspaugh, M.A. and Wise, R.J.: The Design and Operation of an Underground Conveyor Utilizing Intermediate Booster Drives with DC Motors and Controls; Conveyor Belt Engineering for the Coal and Mineral Mining Industries, Society for Mining, Metallurgy and Exploration, Inc., 1993.

[4] Belt Conveyors for Bulk Materials, Conveyor Equipment Manufacturers Association, 5th Edition, 1999.

[5] Funke, H.: The dynamic stress of conveyor belt systems during starting and stopping; Braunkohle Vol 26 (1974) No 3.

[6] O'Donovan, E.J.: Dynamic Analysis- Benefits for all Conveyors; Conveyor Belt Engineering for the Coal and Mineral Mining Industries, Society for Mining, Metallurgy and Exploration, Inc., 1993.

[7] Sollars, P.K., Brady, E.J. and Alspaugh, M.A.: Twentymile Coal Company's Underground Conveyance System; Presented at Min-Expo 2000, Las Vegas, NV, USA, September 2000.